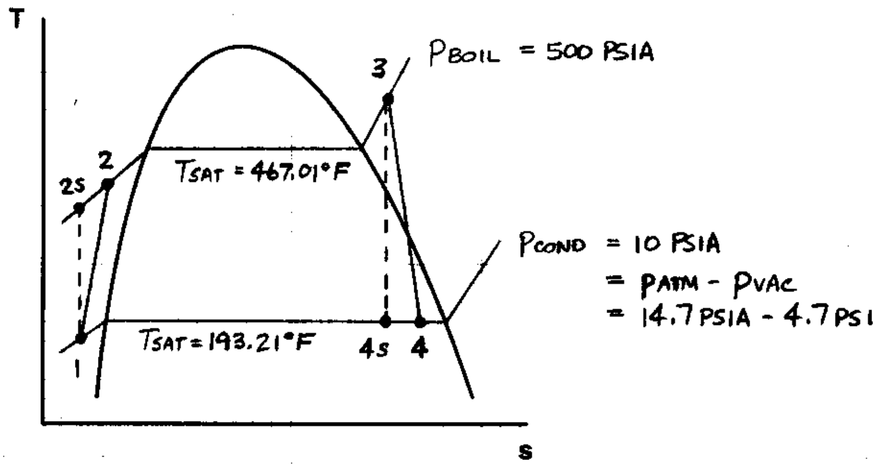
STEAM PLANT WITH COMPONENT EFFICIENCIES

A steam plant generates steam at 500 psia and 550°F. The condenser is maintained at a vacuum pressure of 4.7 psi. Condensate is measured at 188°F at the condenser exit. The feed pump circulates feed water at a rate of 200,000 lb_m/hr. The Higher Heating Value of the fuel is 18,500 Btu/lb_m. The feed pump is 90% efficient. The turbine is 94% efficient. The boiler is 96% efficient.

Find:
- a) amount of condensate depression [°F]
- b) pump work [Btu/lb_m]
- c) turbine work [Btu/lb_m]
- d) cycle thermal efficiency [%]
- e) steam plant net power [hp]
- f) fuel mass flow rate [lb_m/hr]



NOTE: (1) PT 3 IS SUPERHEATED BECAUSE 550°F EXCEEDS T_{SAT} = 467.01°F @ 500 PSIA

(2) PT 1 IS SUBCOOLED BECAUSE 188°F IS LESS THAN T_{SAT} = 193.21°F @ 10 PSIA

a) AMOUNT OF CONDENSATE DEPRESSION (ie AMOUNT OF SUBCOOLING OF THE CONDENSATE)

$$T_{SUBCOOL} = T_{SAT}(@\,p_{COND}) - T_1 = 193.21°F - 188°F$$

$$\boxed{T_{SUBCOOL} = 5.21°F}$$

CALCULATE ALL ENTHALPIES NEXT:

① $h_1 = h_f\ @\,(T_1 = 188°F)$, NOTE: $h_1 \neq h_f\ @\ 10\ PSIA$

$\underline{h_1 = 156.03\ Btu/LBm}$, $v_1 = v_f\ @\ 188°F = .016559\ FT^3/LBm$

(2s) $h_{2s} = h_1 + w_p = h_1 + v_1(p_2 - p_1)\frac{144}{778} = 156.03 + (.016559)(500-10)(\frac{144}{778})$

$\underline{h_{2s} = 157.53\ Btu/LBm}$

② $\eta_p = \frac{h_{2s} - h_1}{h_2 - h_1} = .90 = \frac{157.53 - 156.03}{h_2 - 156.03} \Rightarrow \underline{\underline{h_2 = 157.70\ Btu/LBm}}$

③ $h_3 = h\ @\ 500\ PSIA,\ 550°F$ (TABLE 3)

$\underline{\underline{h_3 = 1267.0\ Btu/LBm}}$, s_3 (TABLE 3) $= 1.5284\ Btu/LBm\,°R$

(4s) STEP 1: $s_3 = s_4 = s_f + x_{4s}(s_{fg})$ NOTE: s_f AND s_{fg} FROM TABLE 2 @ 10 PSIA

$1.5284 = .2836 + (x_{4s})(1.5043)$

$x_{4s} = .8275$

STEP 2: $h_{4s} = h_f + x_{4s}(h_{fg})$ NOTE: h_f AND h_{fg} FROM TABLE 2 @ 10 PSIA

$= 161.26 + (.8275)(982.1)$

$\underline{\underline{h_{4s} = 973.9\ Btu/LBm}}$

④ $\eta_T = \frac{h_3 - h_4}{h_3 - h_{4s}} = .94 = \frac{1267.0 - h_4}{1267.0 - 973.9} \Rightarrow \underline{\underline{h_4 = 991.5\ Btu/LBm}}$

b) PUMP WORK, w_P:

$$w_P = h_2 - h_1 = 157.70 - 156.03$$

NOTE: USE h_2 NOT h_{2s}

$$\boxed{w_P = 1.67 \text{ Btu/LBm}}$$

c) TURBINE WORK, w_T:

$$w_T = h_3 - h_4 = 1267.0 - 991.5$$

NOTE: USE h_4 NOT h_{4s}

$$\boxed{w_T = 275.5 \text{ Btu/LBm}}$$

d) CYCLE THERMAL EFFICIENCY, η_{TH}:

$$\eta_{TH} = \frac{w_{NET}}{q_s} = \frac{w_T - w_P}{q_s}$$

$$q_s = h_3 - h_2 = 1267.0 - 157.70$$

$$q_s = 1109.3 \text{ Btu/LBm}$$

$$\eta_{TH} = \frac{275.5 - 1.67}{1109.3}$$

$$= \frac{273.83}{1109.3}$$

$$\boxed{\eta_{TH} = 24.7\%}$$

e) STEAM PLANT NET POWER [HP]:

$$\dot{W}_{NET} = \dot{m}_{STM}(w_{NET})$$

← NOTE: IF TURBINE POWER WAS ASKED INSTEAD, USE w_T

$$= 200{,}000 \text{ LBm/HR } (273.83 \text{ Btu/LBm})$$

$$= 54.766 \times 10^6 \frac{\text{Btu}}{\text{HR}} \left(\frac{1 \text{ HP}}{2545 \text{ Btu/HR}}\right)$$

$$\boxed{\dot{W}_{NET} = 21{,}519 \text{ HP}}$$

f) FUEL MASS FLOW RATE, $\dot{m}_{FUEL}$:

$$\eta_{BOIL} = \frac{\dot{m}_{STM}(q_s)}{\dot{m}_{FUEL}(HHV)}$$

$$.96 = \frac{200{,}000 \text{ LBm/HR } (1109.3 \text{ Btu/HR})}{\dot{m}_{FUEL}(18{,}500 \text{ Btu/LBm})}$$

$$\boxed{\dot{m}_{FUEL} = 12{,}492 \text{ LBm/HR}}$$